

Mechanisms for Efficient Cloud Markets

A. Bestavros

Computer Science Department
Boston University

In collaboration with

V. Ishakian (BU), J. Londono (BU → U Pontificia Bolivariana), Ray Sweha (BU),
Nikos Laoutaris (BU → Telefonica Research), and S. Teng (BU → USC)



<http://www.cs.bu.edu/groups/wing>

IEEE and RIT, Rochester, NY
December 18, 2012

Cloud Computing: A Paradigm Shift



□ Holistic system (social) view is passé

- Tenants make resource acquisition decisions; no incentive to be fair or friendly to others
- IaaS providers have no incentive to minimize tenant costs; they only react to market pressure
- Challenge is to design the mechanisms that engender trust in the cloud marketplace

□ Marketplace mechanisms

- Fixed pricing for reserved resources
- Fixed pricing for shared resources
- Dynamic pricing for reserved resources

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Fixed pricing for exclusive resources



Infrastructure Services
Amazon Elastic Compute Cloud (Amazon EC2)
Amazon SimpleDB
Amazon Simple Storage Service (Amazon S3)
Amazon Simple Queue Service (Amazon SQS)
AWS Premium Support
Payments & Billing

Home > Products > Amazon Elastic Compute Cloud (Amazon EC2)

Amazon Elastic Compute Cloud (Amazon EC2) BETA

"Pricing is per instance-hour consumed for each instance type. Partial instance-hours consumed are billed as full hours."

Amazon EC2 pricing is per instance-hour consumed for each instance type. Partial instance-hours consumed are billed as full hours.

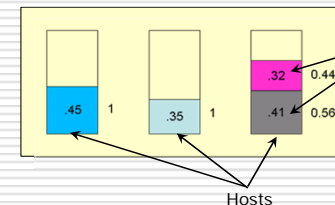
12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

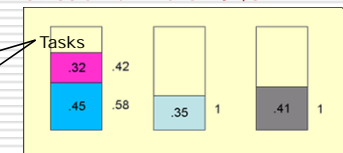
Marketplace Implications?



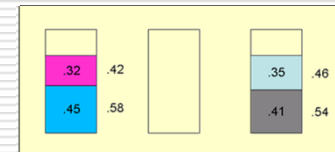
08:00 am / Amazon ← \$3



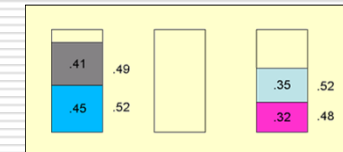
09:00 am / Amazon ← \$3



10:00 am / Amazon ← \$2



11:00 am / Amazon ← \$2



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

(Cloud) Colocation Games



- ❑ IaaS cloud providers offer fixed-sized instances for a fixed price
- ❑ Provider's profit = number of instances sold; no incentive to colocate customers
- ❑ Virtualization enables colocation to reduce costs without QoS compromises
- ❑ Customers' selfishness reduces the colocation process to a strategic game

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Colocation Games: Questions



- ❑ Does it reach equilibrium?
- ❑ If so, how fast?
- ❑ If so, at what price (of anarchy)?
- ❑ How about multi-resource jobs/hosts?
- ❑ How about multi-job tasks?
- ❑ How about job/host dependencies?
- ❑ How could it be implemented?
- ❑ How would it perform in practice?
- ❑ ...

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Colocation Game: Model



- ❑ A hosting graph $G=(V,E)$
 - V & E labeled by capacity vector R and fixed price P
- ❑ Workloads as task graphs $T_i=(V_i,E_i)$
 - V_i & E_i labeled by a utilization vector W
- ❑ Valid mappings
 - $V_i \rightarrow V$ & $E_i \rightarrow E$: $\Sigma W \leq R$; supply meets demand
- ❑ Shapley Cost function
 - Cost P of a resource is split among workloads mapped to it in proportion to use

$$c_M(T_i) = \sum_{j \in \{V_i, E_i\}} P_j \frac{w_{ij}}{U_j}$$

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The General Colocation Game (GCG)



- ❑ GCG is a pure strategies game:
 - Each workload is able to make a (better response) "move" from a valid mapping M into another M' so as to minimize its own cost
- ❑ Example applications:
 - Overlay reservation, e.g., on PlanetLab
 - CDN colocation, e.g., on CloudFront

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

General Colocation Game: Properties



- GCG may not converge to a Nash equilibrium

□ Theorem:

Determining whether a GCG has a Nash Equilibrium is NP-Complete (by reduction to 3-SAT problem)

- Need more structure to ensure convergence



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Colocation Games: Variants



□ Process Colocation Game (PCG):

Each workload consists of a single vertex (process) that needs to be assigned to a single host with only one capacitated resource

□ Multidimensional PCG (MPCG):

Same as PCG but with multi-capacitated resources

□ Example applications:

- VM colocation, e.g., on a Eucalyptus cluster
- Streaming server colocation

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Colocation Games: Variants



□ Parallel PCG (PPCG):

Task graph consists of a set of disconnected vertices (independent processes), each with multidimensional resource utilization needs

□ Uniform PPCG:

Same as PPCG but with identical resource utilization for all processes

□ Example applications:

- Map-Reduce paradigm
- MPI scientific computing paradigm

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Colocation Games: Theoretical results



- PCG converges to a Nash Equilibrium under better-response dynamics
- PCG converges to a Nash Equilibrium in $O(n^2)$ better-response moves, where $n = |V|$
- Price of Anarchy for PCG is 3/2 when hosting graph is homogeneous and 2 otherwise
- MPCG converges to a Nash equilibrium under better-response dynamics
- Uniform PPCG converges to a Nash equilibrium under better-response dynamics
- ...

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

PCG: Better Response



Best-Response moves require knowledge of utilizations of all processes – not practical

Local Better-Response solution:

1. Select a random target hosting node and obtain process utilizations of all processes on that node
2. Determine if a cost-reducing “legal” move to that node is possible – an NP-hard Knapsack problem
 - Dynamic Programming solution in pseudo-polynomial time for small number (100s) of processes/host [DPKP]
 - Breadth-First branch & bound Search heuristic [BFS]
 - Depth-First branch & bound Search heuristic [DFS]

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

PCG: Performance Evaluation



Workloads

- Trace-driven: CoMon PlanetLab Traces
 - Real hosting environment with 3-dimensional resource utilizations
 - Infeasible to compute optimal colocation
- Synthetic: Perfectly Packable
 - Allows systematic exploration of the space
 - Optimal colocation is known by construction

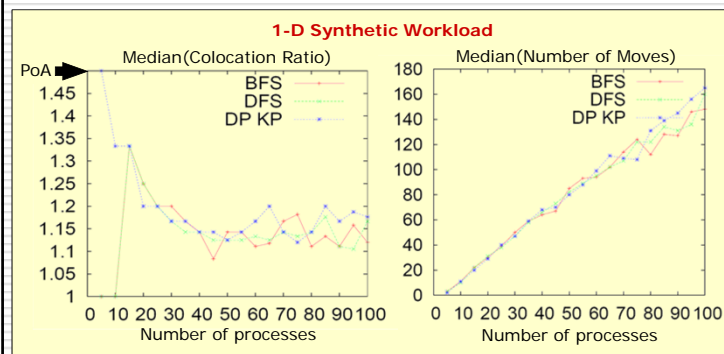
Metrics (over 100 experiments)

- Colocation Ratio (bounded by PoA)
 - How inefficient is the resulting colocation compared to optimal or best?
- Number of moves (not migrations) until NE is reached
 - How much churn (overhead) to be expected?

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

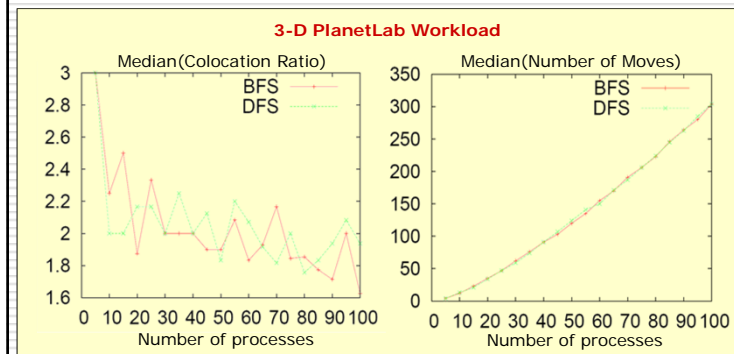
PCG: Synthetic baseline results



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

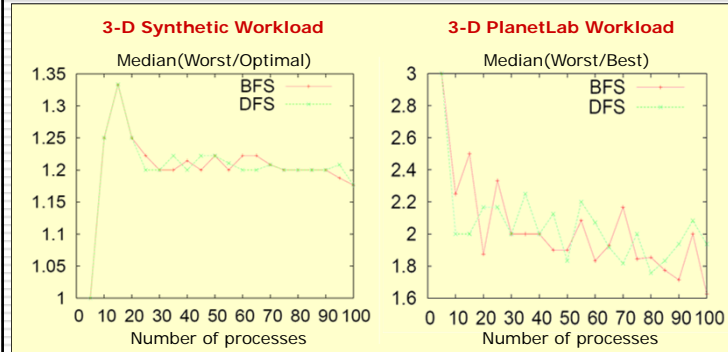
MPCG: PlanetLab baseline results



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

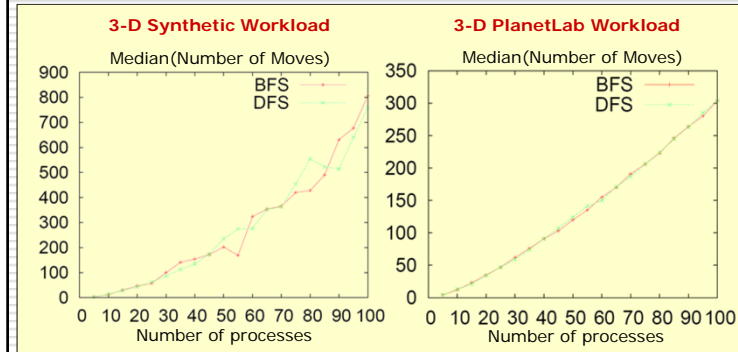
MPCG: Colocation Ratio



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

MPCG: Number of Moves



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The CLOUDCOMMONS prototype



□ API for Strategic Services

To facilitate colocation, e.g., allow users to find each other, compute strategic responses, ...

□ API for Operational Services

To enforce outcomes of colocation, e.g., migration, reconfiguration, accounting, ...

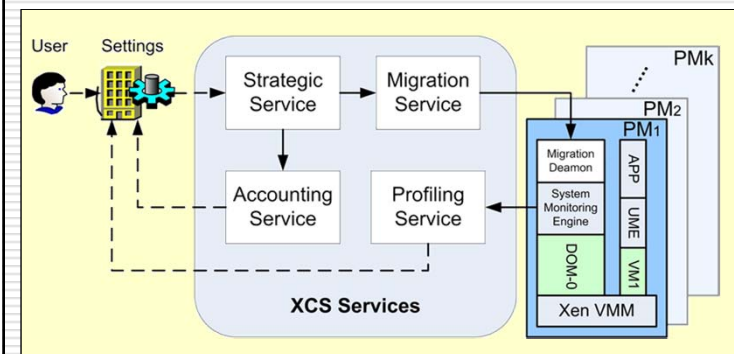
□ Implementation over Xen

Xen Colocation Services (XCS)

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

CLOUDCOMMONS: XCS Architecture



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

CLOUDCOMMONS: Migration Service



□ Identify VMs to migrate

- Minimize number of migrations
- Minimize amount of data that needs to move

□ Determine migration plan

- Exploit potential for parallelism
- Minimize need for staging hosts

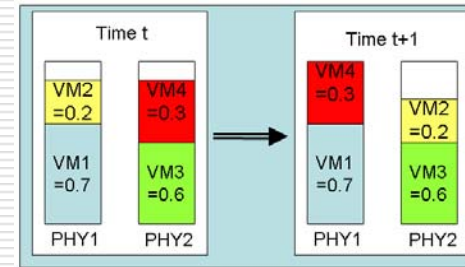
□ Evaluate impact of migration

- On performance of the migrating VMs
- On performance of non-migrating VMs

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Need for staging hosts

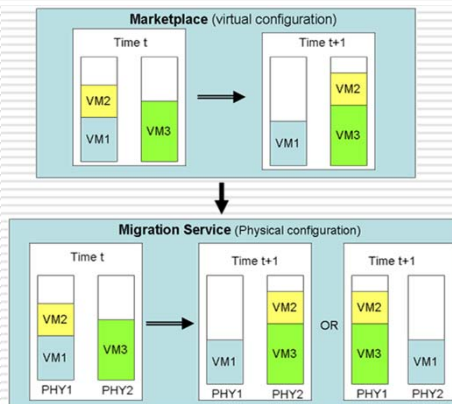


A temporary (staging) host is needed to swap VM2 and VM4

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

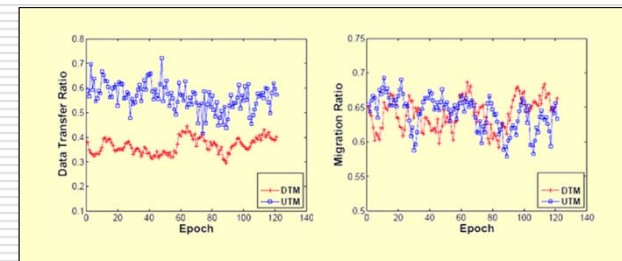
Need for a migration plan



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Data/User Transfer Minimization

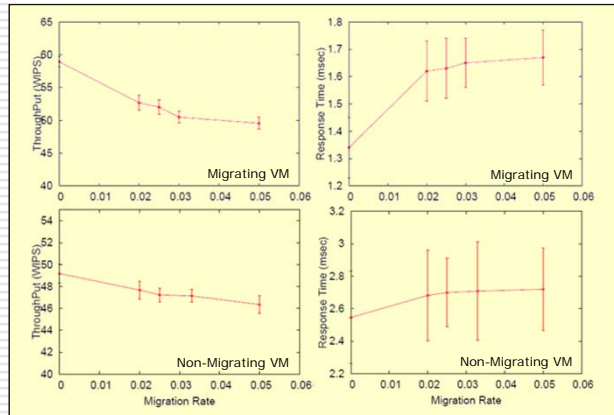


Theorem: The DTM (UTM) heuristic results in at most twice the amount of data transfer (migrations) incurred by an optimal algorithm.

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

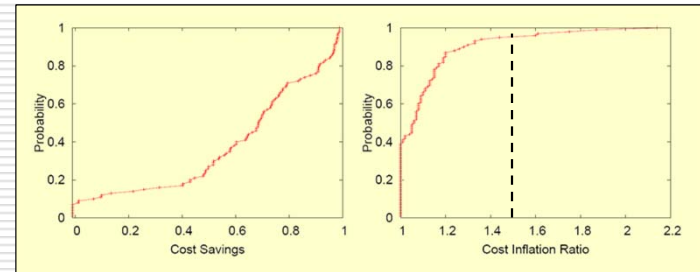
Impact on TPC-W from migration



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

CLOUDCOMMONS: Benefit to users

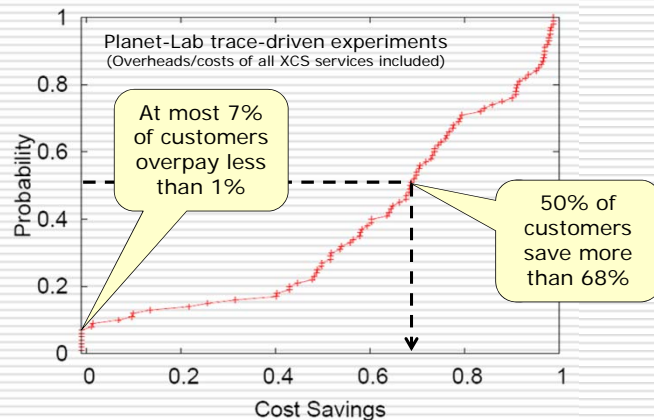


Planet-Lab trace-driven experiments
(Overheads/costs of all XCS services included)

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

CLOUDCOMMONS: Benefit to Customers



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

How do we depart from prior work?

□ Cooperative cost-sharing games^{†##}

- Find coalition where nobody gains by leaving
- Computationally hard
- Applied to best-effort routing problems
- Player cost not use based; unjustifiable

[†] V. Misra, S. Ioannidis, A. Chaintreau, and L. Massoulié. *Incentivizing Peer-Assisted Services: A Fluid Shapley Value Approach*. In SIGMETRICS 2010.

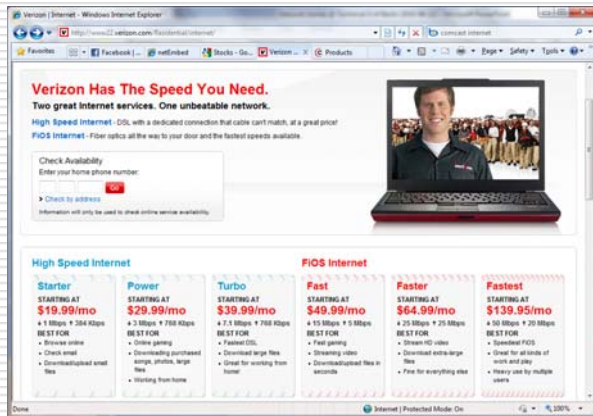
[‡] H. Chen and T. Roughgarden. *Network design with weighted players*. In SPAA 2006.

[#] E. Anshelevich, A. Dasgupta, J. Kleinberg, E. Tardos, T. Wexler, and T. Roughgarden. *The price of stability for network design with fair cost allocation*. In FOCS 2004.

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Fixed pricing for shared resources



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The perils of the fixed pricing model



□ It's here to stay; metered pricing rejected

□ Implications:

- Customer has no incentive to save bandwidth
- ISP cost depends on peak demand – 95/5 rule
- Reigning in bandwidth hogs is incompatible with Net Neutrality

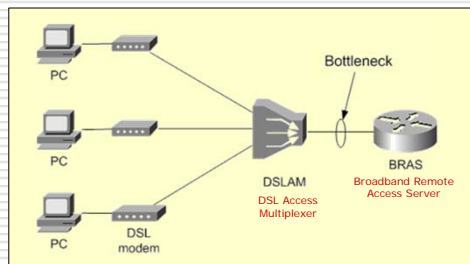
□ Must devise mechanisms that take ISPs out of the “traffic shaping” business

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

30

DSLAM “last-mile” architecture



Traffic shaping done at BRAS

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Solution: Create a marketplace



□ Recognize the two types of user utilities:

- Interactive Traffic (IT)
 - Browsing, VoIP, Video, Messaging, Gaming, ...
 - Limited bandwidth; highly sensitive to response time
- Fluid Traffic (FT)
 - P2P, Network backup, Netflix/software downloads, ...
 - Open-ended bandwidth; less sensitive to response time

□ Create a marketplace:

1. Give users rights to DSLAM bandwidth, and
2. Let users trade IT & FT allocations over time

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The Marketplace



□ Each user gets a fixed budget per epoch

- Budget (B_i) proportional to level of service
- An epoch is a fixed number of time-slots, e.g., 1 day = 288 5-min slots

□ Trade & Cap

- User engages in a pure strategies game that yields a schedule for its IT sessions
- User acquires as much FT bandwidth as its remaining budget would allow

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trading Phase: Strategy Space



□ Session:

An IT session is the sequence of slots during which an IT application is active

□ Slack:

User may have flexibility in scheduling IT sessions; slack specifies the number of slots that an IT session is allowed to be shifted back/forth

□ Strategy Space:

The set of all possible arrangements of IT sessions within allowable slack define the strategy space for a user

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trading Phase: Cost Function



- Let x_{ik} be the bandwidth used in slot k by a chosen IT session schedule for user i .

- The cost incurred by user i is given by:

$$c_i = \sum_{k \in \text{slots}} x_{ik} \cdot U_k = \sum_{k \in \text{slots}} x_{ik} \left(\sum_{j \in \text{users}} x_{jk} \right)$$

- Cost of user i depends on the choices made by other users – hence the game!

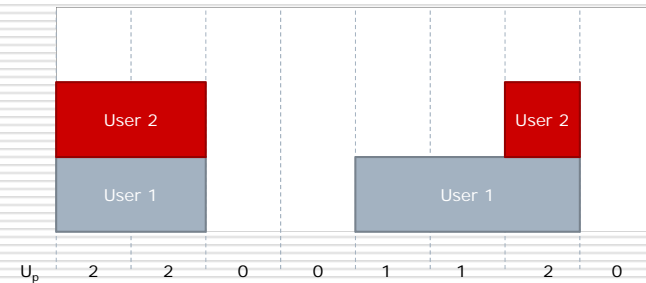
12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trading Phase: Illustration



$$\text{Cost}(\text{User 2}) = 2 \cdot 2 + 1 \cdot 2 = 6$$



12/18/2012

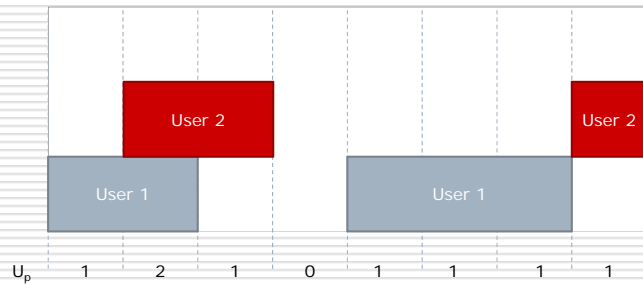
A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

36

Trading Phase: Illustration



$$\text{Cost}(\text{User 2}) = 1 \cdot 2 + 1 \cdot 1 + 1 \cdot 1 = 4$$



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trading Phase: Best Response



- ❑ BR of user i is the schedule of IT sessions that minimizes its cost c_i
- ❑ Computing BR is NP-hard, equivalent to solving a generalized knapsack problem
- ❑ Dynamic programming solution is pseudo-polynomial in the product of the number of sessions and number of slots
- ❑ Scales well for all practical settings – 100s of users and 100s of slots

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

38

Trading Phase: Findings



- ❑ Provably converges to Nash Equilibrium, even in presence of constraints
- ❑ For n users, Price of Anarchy is n , but in practice below 2, especially for $n > 10$
- ❑ Experimentally, large reduction of peak utilization, even with small flexibility

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Capping Phase: Best Response



- ❑ BR of user i is to maximize total FT allocation

$$w_i = \sum_{k \in \text{slots}} w_{ik}$$

subject to the budget constraint

$$\sum_{k \in \text{slots}} w_{ik} \cdot \left(U_0 + \sum_{j \in \text{users}} w_{jk} \right) = B_i - c_i$$

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Capping Phase: Budget



- ❑ Let V be an upper-bound on traffic per slot
- ❑ The ISP sets a target capacity $C = V/R$, where $R \geq 1$ reflects its “resistance” to traffic
- ❑ The ISP allocates C in some proportion (e.g., equally) to all n users over all slots
- ❑ This constitutes the budget B assigned to a user over an epoch T

$$B = \frac{C}{n} \cdot T$$

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Capping Phase: Findings



- ❑ Computing BR is efficient using Lagrange Multipliers method
- ❑ Provably, converges to a unique global (social) optimum that maximizes the FT allocations of all users
- ❑ Experimentally, smoothes the aggregate IT+FT traffic to any desirable level controlled by a “resistance parameter” R

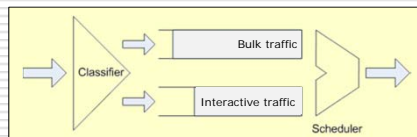
12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trade & Cap: Implementation



- ❑ On Client Side (e.g., DSL Modem):
 - + Strategic agent to execute Trade & Cap
 - + Operational service to profile, classify, and shape

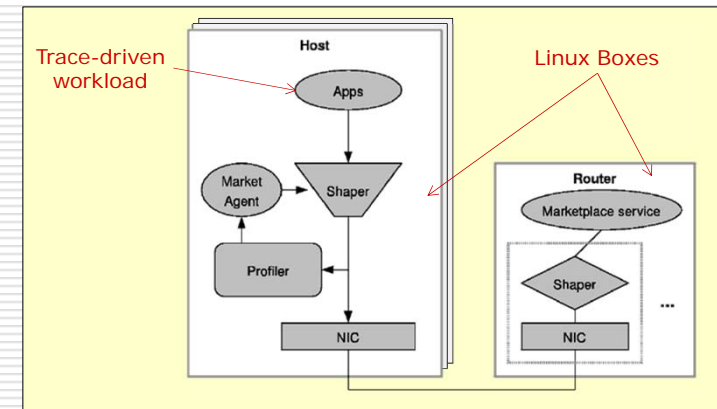


- ❑ ISP Side (e.g., DSLAM or BRAS):
 - + Support exchange between strategic agents
 - + Enforce total traffic/slot/user from Trade & Cap

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trade & Cap: Implementation



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trade & Cap: Implementation notes



□ User Input:

- As simple as checking box to join marketplace, and as elaborate as micromanaging RT slacks
- May set a fraction of “budget” as insurance

□ Client-side Profiler:

- May be explicitly controlled by applications (or user settings)

□ Client-side Traffic Shaper:

- Work-conserving (not reservation based) Linux Hierarchical Token Bucket (HTB)
- Allows FT to use underutilized RT bandwidth

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Experimental Evaluation

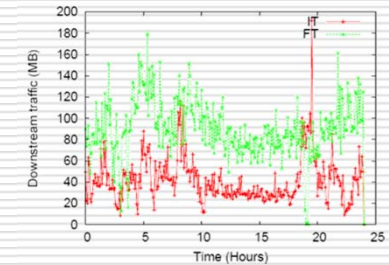


Workload

Derived from WAN traces of MAWI project

Period	2009-03-31 00:00 – 2009-03-31 23:59
Total packets	1,551,089,845
TCP packets	1,194,409,653
UDP packets	4,321,852
Total TCP bytes (payload)	924,540,189,060

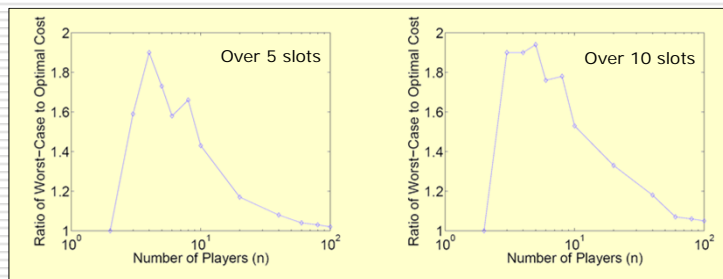
- Identify users from volume and direction of flows to known ports (e.g., most traffic destined to port 80)
- Identify user IT sessions using thresholds on per-IP traffic intensities over time
- Slack introduced using various models (e.g., fixed, proportional, etc.)



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trading Phase: Experimental PoA



Theoretical PoA is n but not in practice

12/18/2012

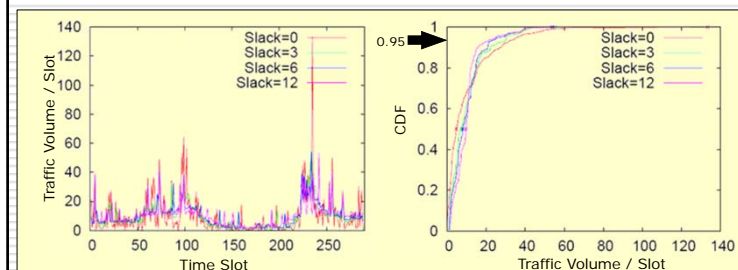
A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trading Phase: Smoothing effect



Value proposition to ISPs

Max Slack	Reduction in 95%
3	15%
6	24%
12	31%



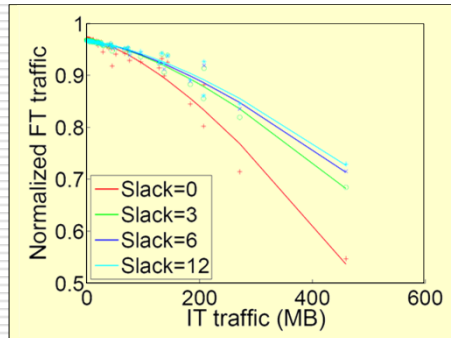
12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trade & Cap: Flexibility pays off!



Value proposition to customers



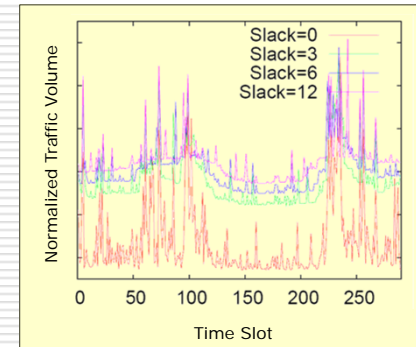
12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trade & Cap



A win-win for ISPs and customers



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Trade & Cap: Beyond DSLAMs



Trade & Cap is a general mechanism

It can be used to coordinate how a shared resource is used by selfish parties who are not subject to the "pay as you go" model – e.g., "fixed pricing"

Examples

- Coordinating consumption of "reserved" versus "fluid" (CPU/network) capacities of VMs sharing a single host
- Coordinating "reserved" versus "fluid" bandwidth utilization by multiple ISP customers (e.g., enterprises)

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Fixed Pricing: Alternatives?



Vickrey-style auctions work[†]

- Assumes supply < demand
- Takes a social perspective
- Offers a strategy-proof solution
- Requires central authority
- Susceptible to collusion

[†] A. Young, B. Chun, A. Snoeren, and A. Vahdat. *Resource allocation in federated distributed computing infrastructures*. In *OS/architectural support for on-demand IT infrastructure*, 2004.

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Dynamic pricing: Better mechanism?



- Customer cost should be a function of supply and demand
 - Supply may vary over time
 - Supplier's cost may vary over time
 - Demand may vary over time
 - Demand may exhibit structure, and may be subject to malleable constraints
- Need language to specify supply and demand (and act as basis for SLAs)

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Resource Supply/Demand Model



- Supply/demand SLA types: (C, T, D, W)
 - C ~ amount available or consumed
 - T ~ allocation period
 - D ~ tolerable number of missed allocations in W
 - W ~ window of ≥ 1 allocation intervals
- Examples
 - SLA type $(2, 5, 0, 1)$
2 resource units supplied/consumed every 5 seconds with no missed allocations allowed
 - SLA type $(3, 30, 2, 5)$
3 resource units supplied/consumed every 30 seconds with no more than 2 out of 5 missed allocations

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

SLA Calculus



- Models various patterns of allocation and consumption (e.g., RR, GPS, LB, ...)
- SLA types define type hierarchies
 - $(1, N, 0, 1) < (k, k * N, 0, 1)$
 - $(C, T, D, W) < (C, T, D', W)$, if $D < D'$
 - ...
- Possible to transform SLAs from one form to another (safer) form

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Using SLA Calculus for Colocation



- Not possible to colocate

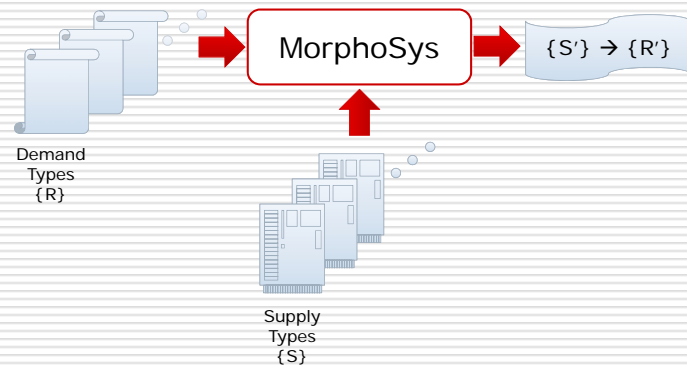
	Job 1	Job 2	Job 3	Job 4	Job 5
C	1	2	3	4	5
T	4	9	17	34	67

- Possible to colocate

	Job 1	Job 2	Job 3	Job 4	Job 5
C	1	2	3	4	5
T	4	8	16	32	64

- SLA types and calculus provide a notion of supply & demand elasticity

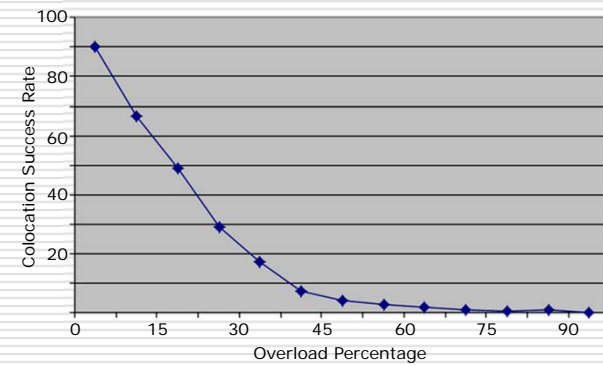
Morphing SLAs for Efficiency



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

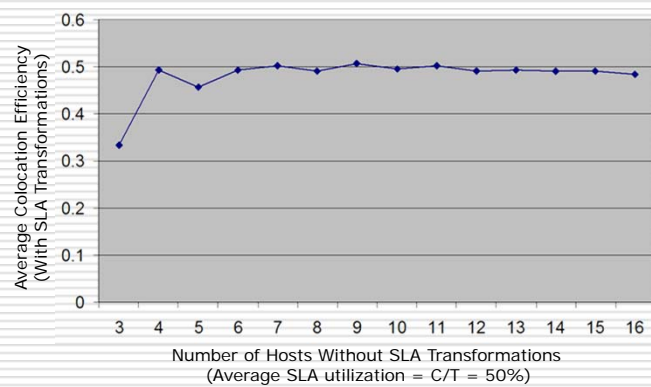
MorphoSys: Success Rate



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

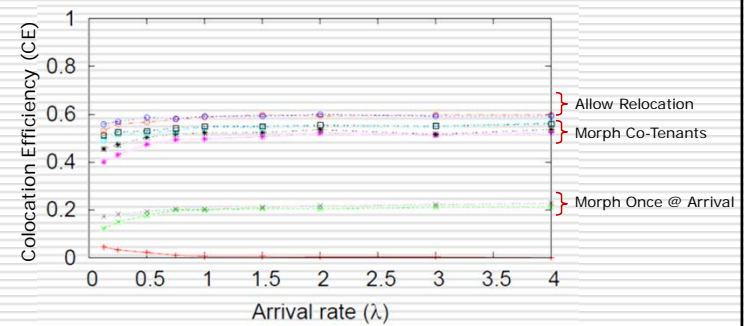
MorphoSys: Co-location Efficiency



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

MorphoSys: Performance



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Beyond Simple Types



□ A workload is a set of requests (tasks), each with its SLA, subject to constraints:

- Temporal dependencies between tasks
- Start and end times

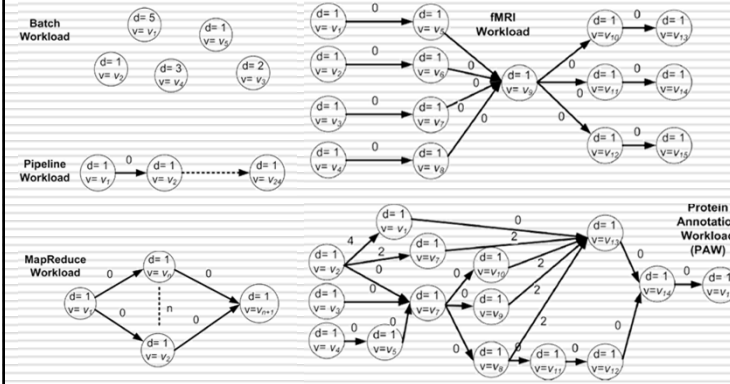
□ Flexibilities might exist; another source of elasticity:

- Min and max delays between tasks
- Deadline slacks

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Workload = DAG of SLA types



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The Customer's Perspective



□ Why should customers expose the elasticity of their workloads?

□ Current IaaS (fixed) pricing mechanisms do not provide proper incentives

□ Implications:

- Less efficient workload management
- Customers (should) game the marketplace

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Dynamic Pricing: Shapley Value



□ Well defined concept for fair cost sharing from coalitional game theory

- Marginal contribution to the total cost, averaged over every permutation, e.g., for 3 workloads

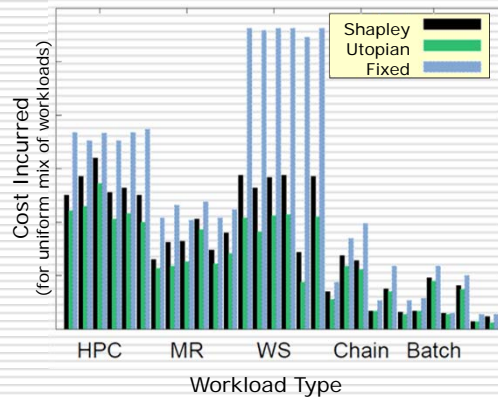
$$s(w_1) = \frac{1}{6} \left(2c(w_1) + [c(w_2w_1) - c(w_2)] + [c(w_3w_1) - c(w_3)] + [c(w_2w_3w_1) - c(w_2w_3)] + [c(w_3w_2w_1) - c(w_3w_2)] \right)$$

- Impractical to calculate
- Estimate by sampling random permutations

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

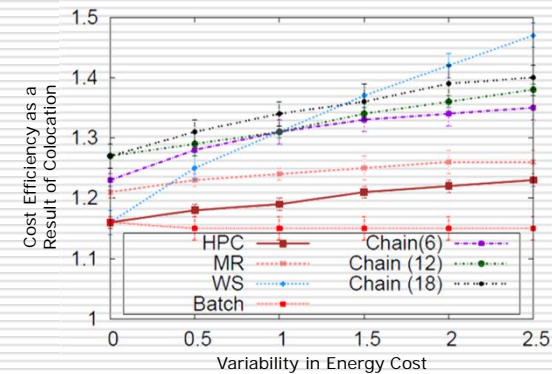
Workload Elasticity = Savings



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Workload Elasticity = Savings



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

CLOUDCOMMONS: <http://csr.bu.edu/cc>



Supported by a NSF Large CyberTrust Award (in collaboration with Brown and UCI)

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Problem with today's cloud solutions

Public clouds are "closed" & prescriptive

- Stock hardware (hard to justify GPUs or a BlueGene)
- Special computational models (MapReduce, or?)
- Operational data is not visible (limits innovation)
- Irrational economic models (why fixed pricing?)
- Designed to lock in customers
- Perform poorly on HPC and big data
- Not conducive to federation of data assets
- Security by obscurity

Not conducive to experimentation/innovation

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Can we change this status quo?



Need an ecosystem for

- Infrastructure Providers
EMC, IBM, Dell, NTAP, Cisco, Intel, AMD, ...
- Software Platforms
VMware, RedHat, Hadoop, Azure, MapReduce...
- Aggregators and Resellers
XCS, Morphosys, CloudPack, ...
- Customers
HPC apps, Web apps, Enterprise, Gov, ...

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

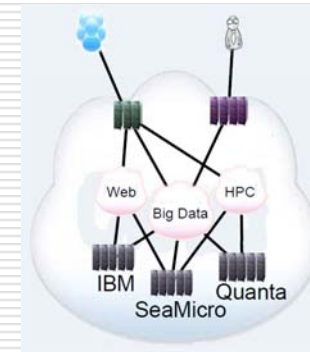
Open Cloud: A Paradigm Shift



Multiple implementation and operational models

- Competing platforms suited to HPC, big data, ...
- Open economic model to create an efficient market
- Operational data visible to various stakeholders

Ecosystem needs a facility for "mashups"



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Massachusetts Green HPC Facility



Ribbon cutting: November 2012
Operational by: February 2013

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The Massachusetts Open Cloud



A non-profit created to operate an open public cloud, with access to 10MW of MGHPCC capacity

- Dedicated user community from BU, Harvard, MIT, NEU & UMass, large startup community
- Rich regional ecosystem, of vendors and customers in specialized domains (big data, HPC, biotech, ...)
- Serves as a repository/infrastructure for regional data/big-data applications
- Significant vendor interest: EMC, Red Hat, IBM, Netapp, MSFT, Intel, AMD, ...
- Strong state support and backing

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

The Massachusetts Open Cloud



An initiative of The BU Hariri Institute for Computing in collaboration with MGHPCC

- Project is spearheaded by Center for Cloud Innovations (Orran Krieger, Director)
- Project leverages three Institute research priorities: Cybersecurity, Big Data, and Cloud Computing

A great vehicle for international collaboration

- Federation interest from GTech, CMU, Brazil, ...

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Conclusion



- Resource management must be seen in an economics context
- By setting up the right mechanisms, one can engender trust in the cloud marketplace
- Supply elasticity meets demand elasticity for an efficient marketplace
- New services needed to support strategic and operational aspects of new mechanisms
- Need to experiment at scale!

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

Paper Trail...

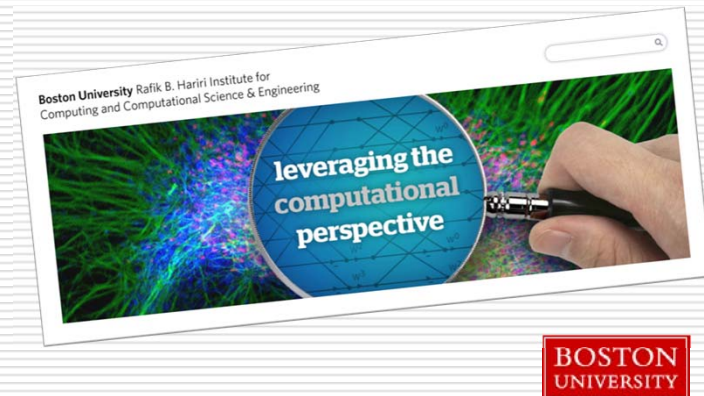


- V. Ishakian, R. Sweha, A. Bestavros, and J. Appavoo. [CloudPack: Exploiting Workload Flexibility Through Rational Pricing](#). In ACM/IFIP/USENIX Middleware Conference, Montreal, Canada, December 2012. (Best Paper Award)
- V. Ishakian and A. Bestavros. [MorphoSys: Efficient Colocation of OoS-Constrained Workloads in the Cloud](#). In CCGrid'12: IEEE/ACM Symposium on Cluster, Cloud and Grid Computing, Ottawa, Canada, May 2012.
- V. Ishakian, A. Lapets, A. Bestavros, and A. Kfoury. [Formal Verification of SLA Transformations](#). In CloudPerf'2011: IEEE International Workshop on Performance Aspects of Cloud and Service Virtualization, Washington DC, 2011.
- V. Ishakian, A. Bestavros, and A. Kfoury. [A Type-Theoretic Framework for Efficient and Safe Colocation of Periodic Real-time Systems](#). In RTSCA'10: IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, pages 143-152, Macau, China, August 2010.
- V. Ishakian, R. Sweha, J. Londono, and A. Bestavros. [Colocation as a Service: Strategic and Operational Services for Cloud Colocation](#). In NCA'10: IEEE Symposium on Network Computing and Applications, Cambridge, MA, July 2010.
- J. Londono, A. Bestavros, and N. Laoutaris. [A Trading System for Fairly Scheduling Fixed-Sized Delay-Tolerant Jobs at a Shared Link](#). In Globecom'10: IEEE Global Telecommunications Conference, Miami, FL, December 2010.
- J. Londono, A. Bestavros, and N. Laoutaris. [Trade and Cap: A Customer-Managed, Market-Based System for Trading Bandwidth Allowances at a Shared Link](#). In NetEcon'10: USENIX/ACM OSDI Workshop on the Economics of Networks, Systems, and Computation, Vancouver, Canada, October 2010.
- J. Londono, A. Bestavros, and S. Teng. [Colocation Games And Their Application to Distributed Resource Management](#). In USENIX HotCloud'09: Workshop on Hot Topics in Cloud Computing, San Diego, CA, June 2009.
- J. Londono and A. Bestavros. [netEmbed: A Network Resource Mapping Service for Distributed Applications](#). In IPDPS'08: IEEE High-Performance Grid Computing Workshop, Miami, FL, April 2008.

12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT

<http://www.bu.edu/hic>



12/18/2012

A. Bestavros -- Mechanisms for Efficient Cloud Markets @ RIT